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Original Article

An ultrasound analysis of the influence of static stretching on fascicle length variation in the gastrocnemius muscle

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Abstract:
Problem Statement: Muscle injuries such as tears often occur when the tendon in the muscle does not properly stretch. The effects of static stretching (SS) on the fascicle length (FL) of the medial gastrocnemius muscle (MG) have not been adequately studied. Earlier investigations on the impact of SS on FL in different muscles have yielded contradictory results. ***Purpose:*** The study aims to determine the association between FL displacement and muscle thickness (MT) variation of MG after SS. Additionally, the study aims to provide a more detailed understanding of how SS affects the muscle elongation (ME), MT, FL and pennation angle (PA) of MG before and after stretching. So, the study provides a more thorough understanding of how stretching affects the mechanical properties of muscles and how it can benefit athletes, the elderly, and patients with certain diseases. ***Approach:*** 20-25 years old 32 healthy males were involved in this experimental study. The variables were measured using ultrasonography equipment with a 15-MHz linear transducer and 38-mm field of view. Data were collected before and after a self-administered SS task of 30 seconds, and five stretching sets were completed. ***Results:*** The results of the linear regression of the study showed that MT strongly influences FL in MG after SS, R^2 = 51%, β=.71, p <.001. A centimetre increment in MT increases FL by approximately 1.18 to 2.54 centimetres. Furthermore, SS statistically significantly impacts MG's FL, MT, and PA (p<.001).
Conclusions: This research investigated the relationship between muscle thickness (MT) and fascicle length (FL) following self-administered static stretching (SS). MT predicted FL significantly, which affects muscle function and performance. SS increased muscle length, FL, and flexibility, but MT and PA decreased significantly. The study's shortcomings encourage more investigation into SS's long-term effects on muscle properties in diverse populations. These findings influence injury prevention, rehabilitation, and performance enhancement in athletes and physically active people.
Keywords: Ultrasound Scan, Static Stretching, Gastrocnemius Muscle, Muscle Thickness, Fascicle Length.

Introduction

Muscle injuries, such as tears, happen when the tendon in the muscle does not properly lengthen, leading to the muscle being damaged or torn. Since this is the case, knowing the mechanism of muscle tendon elongation is essential for treating and preventing these injuries (Titan et al., 2019). During any form of motion, the muscle tendon unit (MTU) is responsible for producing muscular force. The length of the muscle determines whether the generated force is active or passive (Ahmad et al., 2020). Therefore, the quantity of sarcomeres engaged is proportional to the muscle length. Sports and fitness employ stretching to increase flexibility, prevent injuries, and boost performance. Static, dynamic, proprioceptive neuromuscular facilitation (PNF) and ballistic stretching are used. SS is one of the most usual interventions used to increase muscle function and decrease the probability of injury (Bengtsson et al., 2018). However, the effects of SS on the FL of the MG have not been thoroughly investigated.

FL is an essential characteristic of skeletal muscles that can be modified through various training methods. "The distance between the intersection composed of the superficial aponeurosis and fascicle and the intersection composed of the deep aponeurosis and the fascicle is the FL" (Fukutani & Kurihara, 2015). The FL largely determines the mechanical properties of a muscle, such as its capacity to generate force and contraction efficiency. MT and PA are other muscle properties that stretching can alter. The distance between the superficial and deep aponeuroses is what MT means. The PA is the angular distance between the fascicle and the deep aponeurosis (Seynnes & Cronin, 2020). Previous research has shown that SS can decrease muscle strength, power, and neuromuscular activity, possibly due to changes in muscle architecture (Sato et al., 2020). In particular, some studies have suggested that SS can decrease FL (Bouvier et al., 2017). However, most of those studies focused on the effects of SS on the triceps surae muscle group as a whole and not specifically on the MG.

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Non-invasively measuring muscle attributes like FL and MT is now possible with ultrasound imaging. FL and MT can be measured at rest and when the muscle is contracting, and the muscle's architecture can be viewed and studied. Recent studies have used ultrasound imaging to investigate the effects of SS on FL in other muscles, such as the biceps brachii, triceps brachii, hamstring and quadriceps muscles. These studies have reported mixed results, with some finding a decrease in FL following stretching (Esposito et al., 2019). However, Nelson and colleagues (2016) found there is no significant FL change after SS.

Additionally, these studies have been performed on healthy adults and athletes, and the effects of stretching on the muscle properties of specific population groups, such as university students, need further investigation. Given the lack of research specifically investigating the effects of SS on the FL of the MG and the conflicting results of previous studies, further research is needed to better understand the impact of SS on this muscle. Ultrasound analysis of the MG would provide valuable information on the effects of SS on muscle architecture and may have implications for using stretching as a therapeutic intervention and in training programmes (Van Hooren et al., 2020).

The main objective of this research was to determine the association between FL displacement and MT variation in the MG after SS among selected male subjects from a private university in Malaysia. An improved understanding of the effects of stretching on the MG can lead to better injury prevention and rehabilitation programmes (Kim et al., 2018). In addition, it helps the development of more effective stretching routines, which can benefit various population groups, including athletes, elderly individuals, and patients with certain conditions. The study also aims to provide a more detailed understanding of how stretching affects the ME, MT, and PA of MG before and after SS.

Material & methods

This experimental research was conducted at a private university in Malaysia. Thirty-two healthy male subjects within the age group of 20-25 were selected. The subjects had neither a lower extremity injury (ligament or muscle rupture) nor an unhealthy Body Mass Index (BMI; normal range: 18.5-24.9 kg/m^2 (Pan & Yeh, 2008). This study excluded participants diagnosed earlier with any neuromuscular problem or musculoskeletal impairment to their lower limbs on either side.

***Data Collection Tools*:**

Tendon movement, ME, MT, and PA were evaluated by a 15-MHz linear transducer and a 38-mm wide field of view (FOV) using Mylab Touch, Esaote, Italy, real-time ultrasonography system. The ultrasound evaluation was performed by a medical ultrasound imaging expert with at least five years of experience in the same field.

Data Collection Process:

All participants acknowledged the procedure and gave their informed consent before the study. Thirty-two healthy males were subjected to SS with adequate rest intervals. Pre-and post-measurements of static elongation were conducted. The self-administered SS task has a time limit of 30 seconds, and the subjects must complete five sets. The subject is to stand straight before a wall, feet parallel, arms resting on the wall. Slanting against the wall will gradually cause the ankle to dorsiflex until a comfortable stretch is reached. ME, MT, and PA were measured before and after the elongation technique. The starting point for the measurement is 30 mm distal to the popliteal fossa and approximately 20 mm medial of the line that divides the medial and lateral gastrocnemius. The PA between the muscle fibres can be seen, and this area's muscle architecture is clearly characterised.

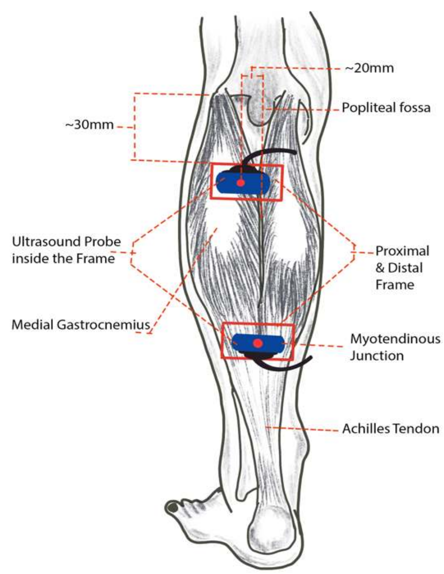

Fig. 1: Ultrasound Probe Position.

Before stretching, each participant had their prominent leg fixed to a proximal, rectangular plastic foam frame. As the ultrasonic probe gathers data from the same spot, it may advance distally through the proximal frame about a quarter of the way superior from the middle of the lateral malleolus to the popliteal fossa. Connectivity between the superficial and deep aponeuroses of the MG was found to occur at the myotendinous junction (MTJ). After that, a distal frame, likewise made of plastic foam but in a rectangular shape, is attached to the ipsilateral calf. The alignment of MTJ using a distal frame is depicted in Figure 1. Once the SS was completed, the ultrasound probe was moved back to the earlier original position to record a new image. In this study, the proximal and distal transducer locations can be used to calculate the MG's overall length, otherwise known as ME. In addition, the collected ultrasound picture can be used to calculate the PA and the thickness of the muscle. The angle at which the fascicles of muscle fibres in MG were inserted into the deeper aponeurosis, or PA, was characterised as shown in Figure 2. FL was computed using a basic trigonometric formula shown below (Blazevich, 2006), and it was found to be the distance between the fascicle's insertions into the superficial and deep aponeuroses.

$$FL = \frac{\text{MT}}{\text{Sin}(\text{PA }\theta)}$$

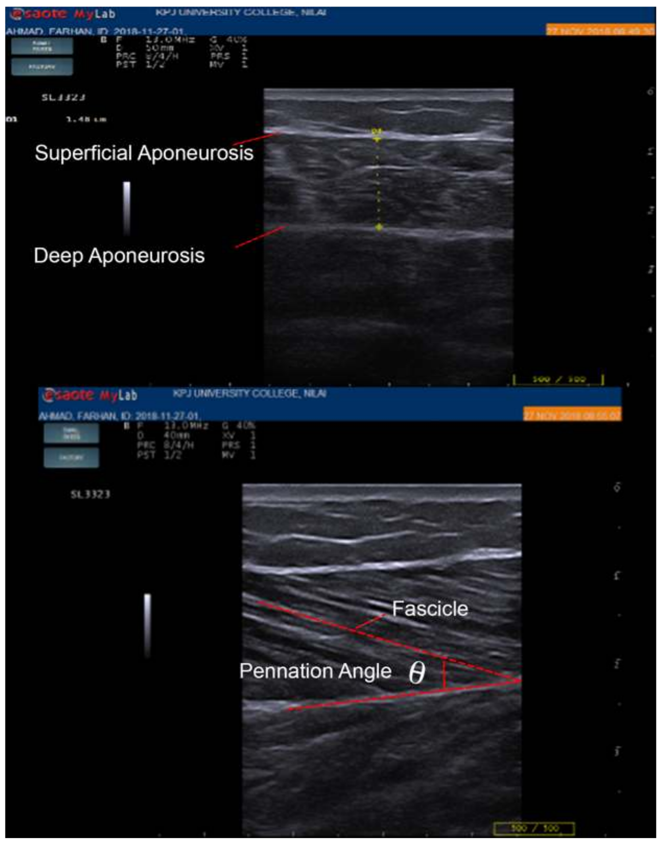

Fig. 2: Ultrasound images of the gastrocnemius (medial) showing MT, PA, and fascicle.

Statistical Analysis:

The collected data were analysed using Microsoft Excel version 19.0 (Microsoft Office 365) and the statistical package for social science (SPSS) version 25.0. Normality tests were performed on the data, and paired sample t-test was used to examine the differences in the means of biomechanical variables like MT, ME, PA, and FL between the pre-and post-static elongation procedures. The relation between FL with ME and MT discrepancies after static elongation manoeuvre were analysed with the Pearson Correlation. After performing the static elongation task, a simple linear regression was carried out to determine the linear relationship between MT and the length of the fascicle.

Ethical Statement:

The ethical statement for this research is that all participants were treated with respect, and their privacy was maintained. A clear and detailed explanation of the study was given to the research participants before deciding whether to participate and adequately consented. Furthermore, any risks and benefits associated with participating in the study were fully disclosed. The Institutional Review Board approved this study with the ethical clearance number KPJUC/RMC/EC/2018/129

Results

The participants were divided into two groups, those with a right-leg dominance pattern and those with a left-leg dominance pattern. Firstly, the study gathered and analysed some basic demographic information. As a result, 94% of the healthy young men who participated utilised their right leg, while just 6% used their left.

Association between MT and FL

A simple linear regression was conducted to examine how well the MT could predict the length of the fascicle, as described in Table 1. An observation of standard residuals revealed that the data did not contain any outliers (Std. Residual Minimum = -1.590, Std. Residual Maximum = 2.682). The independence of residual errors was confirmed using the Durbin-Watson test (d = 2.144). The residual is consistent with homoscedasticity and normality. MT statistically significantly predicted FL, F (1, 30) = 31.147, β=.71, p <.001, accounting for 51% of the variability in FL with adjusted R^2 = 49.3%, as shown in Figure 3, and it is a moderately strong predictive relationship (Cohen, 1988). In addition, Table 2 demonstrated a significant positive association between MT and the length of the fascicle; Pearson's r = 0.714, N = 32; (p = <.001). The regression equation for predicting the FL from MT was $\hat{Y} = 2.18 + 1.86 * (Muscle\ Thickness)$ (Srivastava, 2019). The confidence interval for the slope to predict FL from MT was 95% [Cl 1.178, 2.538] with B = 1.86; therefore, for each centimetre increase in MT, FL increases by about 1.18 to 2.54 centimetres.

Table 1: Linear Regression Analysis Summary for Muscle Thickness predicting Length of Fascicle.

Variable	*B*	*SE*	95% CI	β	t	*p*
(Constant)	2.18	0.46	[1.23, 3.12]		4.70	.000
Muscle Thickness	1.86	0.33	[1.18, 2.54]	0.71	5.58	.000

Note. R^2 adjusted = 0.49. CI = confidence interval for B. N = 32.

Table 2: Correlation Between Fascicle length, Muscle Thickness and Muscle Elongation

	Pearson	
	r	*p*
Fascicle Length – Muscle Thickness	0.714***	.000
Fascicle Length – Muscle Elongation	0.311	.083
Muscle Thickness – Muscle Elongation	0.205	.260

***p<.001

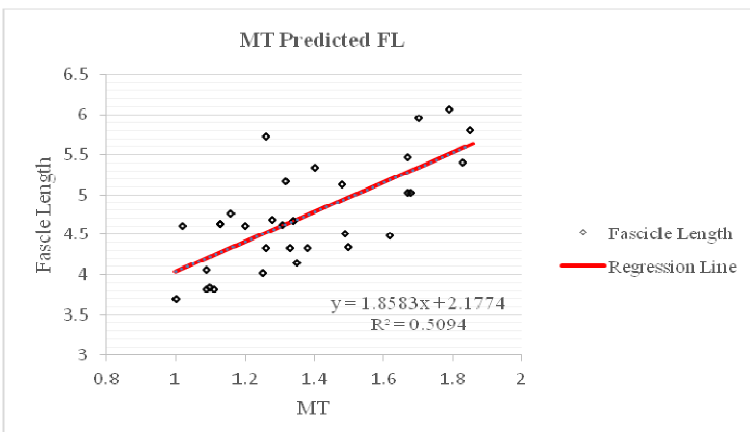

Fig. 3: Scatter plot with Regression line showing muscle thickness predicting fascicle length

Comparison of variables in Pre-and Post- stretching manoeuvres

The results of a paired-sample t-test were then analysed to see how static elongation affected the MG biomechanical variables, as described in Table 3. The result showed that the ME increased significantly from before (M = 18.598, SD = 2.49) to after (M = 19.60, SD = 2.52), t (31) = -9.250, p <.001 (two-tailed). The mean rise in test scores was 1.00 cm, with a 95% confidence interval of -0.779 to -1.220, and the effect size was huge (d = -1.635). The interpretation of the magnitude of Cohen's d values is 0.2: small effect size, 0.5: medium effect size and 0.8: large effect size (Cohen, 1988).

To compare the thickness (cm) of the MG prior to and after the static elongation procedure was statistically analysed by paired-sample t-test. MT declined substantially from before (M = 1.471, SD = 0.259) to after (M = 1.368, SD = 0.248), t (31) = 6.803, p <.001 (two-tailed). The mean reduction in research scores was 0.102 cm, with a 95% confidence interval between 0.072 and 0.133 cm and a significant effect size (d = 1,203). The paired-sample t-test revealed that the PA decreased significantly from before (M = 19.983, SD = 2.683) to after (M = 16.881, SD = 2.150), t (31) = 7.296, p <.001 (two-tailed). The mean reduction in research scores was 3.102 degrees, with a 95% confidence interval between 2.234 and 3.969, and the effect size was substantial (d = 1.290).

The FL before and after the static elongation manoeuvre was calculated from the measurement of MT and PA. In addition, a paired sample t-test was performed to compare the estimated FL before and after the static elongation manoeuvre. There was a significant difference in estimated FL between before (M = 4.335, SD = 0.723) and after (M = 4.720, SD = 0.646); t (31) = -5.044, p <.001 static elongation technique. The mean increase in the test scores was 0.385cm with a 95% confidence interval ranging from -0.229 to -0.541, and d = -0.892 shows a large effect size. A weak, positive correlation existed between the FL and ME after the static elongation task; r =0.311, N = 32; however, the relationship was insignificant (p = 0.083).

Table 3: Summary of paired sample t-test results and effect sizes before and after static elongation of gastrocnemius muscle.

	Before SS		After SS					
	M	SD	M	SD	df	t	*p*	Cohen's d
Muscle Length	18.60	2.49	19.60	2.52	31	-9.25	.000	-1.64
Muscle Thickness	1.47	0.26	1.37	0.25	31	6.80	.000	1.20
Pennation Angle	19.98	2.68	16.88	2.15	31	7.30	.000	1.29
Fascicle Length	4.34	0.72	4.72	0.65	31	-5.04	.000	-0.89

Note. M=Mean, SD= Standard Deviation.

Discussion

In this study, most participants were 20 years old, had a height of approximately 170 cm, weighed approximately 65 kg, and had a BMI range of 22 to 27. Because of the changes in the skeletal muscle composition, the subject's age range was limited to 20 to 25 years. Between the ages of 20 and 40, the mass may remain consistent, but it begins to decrease drastically after the age of 45 (Herbert et al., 2015). Consequently, there are age-related modifications to the tensile properties of muscle fibres. An ultrasound scan measures the distance between the tendon and the muscle, either a lateral or medial positioning technique. Therefore, ultrasonography is an excellent method for determining the change in ME (Barber et al., 2011).

The results of the linear regression analysis in this study indicate that MT is a statistically significant predictor of FL (R^2 = 51%, β=.71, p <.001), and it shows one-centimetre increments of MT increases FL by about 1.18 to 2.54 centimetres. Additionally, there was a significant positive correlation between MT and FL (p = <.001). These findings are consistent with previous research in the field. For example, Baroni and colleagues (2013) found that MT was positively correlated with FL in the rectus femoris (RF) and vastus lateralis (VL) muscles. Another study reported similar results in the gastrocnemius muscle of males aged 19-30 (Simpson et al., 2017). These studies, along with the results of the current study, support the notion that MT plays a vital role in determining FL, which influences muscle function and performance.

On the other hand, some studies present contradictory results. For example, Fukutani and Kurihara (2015) found no significant relationship between MT and FL in the vastus lateralis and gastrocnemius muscle of individuals with regular resistance training experiences. However, the authors suggested this may be due to the highly specialised nature of these muscles in highly trained individuals. Therefore, the results may not generalise to other populations or muscle groups. Another study found that the preferred leg of athletes shows greater MT but not FL (Aeles et al., 2017). The authors suggest that this may be due to the unique architectural characteristics of the preferred leg gastrocnemius muscle. However, our study provides evidence of a moderate to strong predictive relationship between MT and FL. This finding has important implications for research in sports medicine and human physiatry. For example, it could be helpful to understand muscle structure and function, which could help develop therapies and treatments for muscle-related injuries and conditions.

The study's results also indicate that static elongation effectively increased the overall length of the MG; the paired-sample t-test was also statistically significant (p<.001). A study by Nakamura and colleagues (2011) found that SS significantly increased the length of MG in healthy adults, consistent with the current study's results. Another study found that SS increased ME and range of motion in the hamstring muscle group of collegiate athletes (Covert et al., 2010). Similarly, a study by Page (2012) found that SS improved ME and range of motion in the hip flexor muscles and hamstrings of older adults, athletes, and rehabilitation patients. These studies and the current study provide evidence that static elongation can effectively increase ME, which has important implications for using static elongation in clinical and rehabilitation settings. It is worth mentioning that SS has been shown to be more effective than dynamic stretching in increasing ME (Behm et al., 2015).

According to the current research, the statistically significant paired-sample t-test result (p<.001) also shows that static elongation reduced MT from about 0.072 to 0.133mm. This reduction in MT could be related to the increased ME resulting from static elongation. This finding is coherent with recent research by Yahata and colleagues (2021), who found that muscle stretching leads to changes in muscle architecture, such as MT, which could explain the reduction in MT found in the current study. Furthermore, another study found that stretching decreases the PA, which could change muscle function and performance (Simpson et al., 2017). The results of this study also evaluated the PA and indicated a significant decrease in PA after the static elongation procedure (p < .001). This suggests that static elongation can lead to significant changes in muscle architecture, which could affect muscle function and performance.

Finally, this study evaluated the FL of the muscle and found that it increased significantly ($p < .001$) after SS exercise, and it supports the idea that static elongation techniques can effectively improve muscle length. On the other hand, the study also found a weak positive correlation between FL and ME after the static elongation task, but this relationship was not statistically significant ($p = 0.083$). Some previous research supports it, which found that SS increased FL and ME in the quadriceps and plantar flexor of healthy adults but a weak correlation between them (Bouvier et al., 2017). Another study by Kudo and colleagues (2020) reported similar results in the MG of healthy adults. These studies and the current study provide evidence that static elongation can effectively increase FL, which could have important implications for using static elongation in clinical and rehabilitation settings.

Conclusions

In conclusion, this study aimed to investigate mainly the relationship between MT and FL in 20-25-year-old participants after self-administrated SS. One of the critical benefits of this study is that it provides insight into the relationship between MT and FL and shows that MT is a good predictor of FL. This finding is consistent with previous research in the field and suggests that MT plays a vital role in determining FL, which in turn influences muscle function and performance. The study found that self-administered SS substantially affected the morphological and mechanical features of the MG, such as ME, MT, FL and PA. The SS resulted in a decrease in MT and PA than prior SS, indicating muscle fibre rearrangement.

Additionally, the study investigated the effect of SS on ME, and the results indicated that SS was effective in increasing the overall length of the MG. This is supported by previous studies, which have found that SS can increase ME and range of motion in various muscle groups of healthy adults and athletes. This occurs because the elastic qualities of the muscle are diminished as the MTU lengthens under stretch. This research can help inform the development of training programmes that target specific muscle characteristics and aid in evaluating athletes. Even though both FL and ME exhibit a weak positive association, this study could not demonstrate a statistically meaningful interrelationship between the two variables.

The findings indicate that SS can be a helpful approach for improving muscular flexibility and lowering the risk of injury, particularly in people with a lower extremity injury or musculoskeletal dysfunction. Further research is needed, however, to assess the long-term effects of SS on muscle characteristics and to discover the best SS technique for different populations and forms of physical exercise. Overall, this study emphasises the significance of understanding muscle's morphological and mechanical features in response to SS and establishes the foundation for future research in this field. The findings have implications for injury prevention, rehabilitation, and performance enhancement in athletes and physically active individuals. Athletes and trainers are recommended to incorporate SS into their training and warm-up routines to enhance muscle flexibility and reduce the chance of injury. Furthermore, it is critical to continue studying the effects of SS on muscle characteristics to produce evidence-based guidelines for appropriate SS protocols in various populations and forms of physical exercise.

In this investigation, we found some potential constraints. First, the study used a limited sample size of 32 healthy male individuals, limiting the finding's generalizability to broader and more diverse populations. Second, the study only included healthy male individuals in a certain age range from a single private institution in Malaysia. It may limit the study's finding's applicability to other demographics, such as women, the elderly, and people from other geographical areas. Third, there was no control group in the study to compare the effects of static stretching with those of a non-stretching intervention or a different stretching technique. Finally, although ultrasonic imaging is a non-invasive and dependable method for analysing muscle architecture, it may not provide an accurate image of all the muscle's functional qualities.

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Conflicts of interest - The authors hold no relevant financial or non-financial interests. Therefore, the authors declare that they have no conflict of interest.

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